COST Action 272
“Packet-Oriented Service Delivery via Satellite”

*Stratospheric Optical Inter-Platform Links (OIPLs)*
*for High Altitude Platforms*

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STRATOSPHERIC OPTICAL INTER-PLATFORM LINKS (OIPLs) FOR HIGH ALTITUDE PLATFORMS

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Outline:

• Projected HAPs Systems and Inter-Platform Link Scenarios
• Technological Constraints
• Transmittance Properties of the Stratosphere
• Effects of Clear-Air Turbulence on the Optical Link
• Link Budget Results for Typical Scenarios
• Outlook
Projected HAPs Systems
...for provisioning of data-coms services for terrestrial users

Airships:
station-keeping with stable attitude, typically unmanned

*Skystation*: 21km operational altitude, solar powered

Aircraft:
circling aircraft system, 17-20km operational altitude

*HALO*: manned, 3×8h scheme

*HELINET*: unmanned, solar-powered, European IST-project

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**Footprint Diameter for HAPs Coms Service Areas:**

<table>
<thead>
<tr>
<th>HAP-altitude</th>
<th>minimum ground-antenna elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>30km</td>
<td>20°</td>
</tr>
<tr>
<td></td>
<td>161km</td>
</tr>
<tr>
<td>24km</td>
<td>129km</td>
</tr>
<tr>
<td>18km</td>
<td>98km</td>
</tr>
</tbody>
</table>

**Scenario Example:**

30km HAPs altitude
5° / 10° min. ground-elevation
400km OIPL distance
Technological Constraints:
Optical IPL-technology is advantageous over µWave due to its low natural beam divergence and thus superior transmission efficiency

Optical Free-Space Transmission Technology:
Here direct detection (binary Intensity modulation) of high-power multimode-laserdiodes is used

Transmission Wavelength:
Component Availability
Eye-safeness
Low Natural Background-Radiation
No Atmospheric Absorption Lines
Low Turbulence Susceptibility

-> use 1550nm as established in Terrestrial Fiber-Coms

Optical Transceiver Terminals (Telescopes):
Diameter: 20cm (e.g. typical Cassegrain structure)
Tx Divergence: 300µrad (broader than diffraction limit to compensate for platform vibrations)

Cloud Ceiling - Geometric Restrictions (1)

Tropopause defines cloud limit:

Cloud density at 16km:
(SAGE-Satellite Data)

Minimum link graze height (path altitude minimum)
-> 13km for mid latitude regions
Geometric Restrictions (2)

Max. possible distances:

Definition of Scenarios:

<table>
<thead>
<tr>
<th>scenario</th>
<th>HAPs-altitude</th>
<th>OIPL-distance</th>
<th>graze-height</th>
</tr>
</thead>
<tbody>
<tr>
<td>high-long (HL)</td>
<td>30</td>
<td>932</td>
<td>13</td>
</tr>
<tr>
<td>high-short (HS)</td>
<td>30</td>
<td>461</td>
<td>25.7</td>
</tr>
<tr>
<td>med.-short (MS)</td>
<td>24</td>
<td>375</td>
<td>21.25</td>
</tr>
<tr>
<td>low-long (LL)</td>
<td>18</td>
<td>506</td>
<td>13</td>
</tr>
<tr>
<td>low-short (LS)</td>
<td>18</td>
<td>253</td>
<td>16.74</td>
</tr>
</tbody>
</table>
Influence of the Atmosphere on Optical Waves

Attenuation Effects

Index-of-Refraction Effects

Scattering:
- Rayleigh-Scattering
- Electrons-Resonance
- Mie-Scattering
- Aerosols and Droplets

Absorption:
- Molecular Absorption
- Absorption by Aerosols, volcanic ash, and

Free-Space Loss

Clear-Air Attenuation (1)

Molecular Absorption Lines - Pressure Broadening
Clear-Air Attenuation (2)

Aerosol Absorption
(at different levels of volcanic activity)

Typ. Transmittance vs. Wavelength

Influence of the Atmosphere on Optical Waves

Index-of-Refraction-Effects

Local Phase-Distortions due to Index-of-Refraction-Turbulence
depending on link-scenario cause...

Wavefront Distortions
Beam-Broadening
Farfield-Speckle
Beam-Tilt
Angle-of-Arrival Fluctuations

Elevation-Deviation:
differential deviation-wandering due to changing index-of-refraction altitude profile

Clear-Air Turbulence (1)

Index-of-refraction disturbances along the link path cause intensity speckles at the receiver:

Atmospheric Effects on OIPLs:

Clear-Air Turbulence (2)

Typ. simulated speckle pattern 
(24m × 24m)

Perform numerical simulations for the optical field at the Rx, based on known parameters like turbulence-strength profile, size spectrum of turbulence cells, ...

simulation tool “PILab”
(DLR proprietary)
Results of Turbulent Beam Propagation - Simulations:

Simulation Parameters:
Rx telescope diameter: 20cm
transmission wavelength: 1550nm
paths according to the five scenarios
(distances 253 to 932km, graze heights 13 to 25.7km)

<table>
<thead>
<tr>
<th>scenario</th>
<th>free-space loss in dB</th>
<th>atmospheric attenuation in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL</td>
<td>-63</td>
<td>-6.6</td>
</tr>
<tr>
<td>HS</td>
<td>-57</td>
<td>-0.6</td>
</tr>
<tr>
<td>MS</td>
<td>-55</td>
<td>-1.6</td>
</tr>
<tr>
<td>LL</td>
<td>-58</td>
<td>-4.1</td>
</tr>
<tr>
<td>LS</td>
<td>-52</td>
<td>-4.1</td>
</tr>
</tbody>
</table>

Link Budget Results:

Free Space Loss and Atmospheric Attenuation:

Scintillation Loss and Required Tx Power
(including all typical system losses):

<table>
<thead>
<tr>
<th>scenario</th>
<th>scint. loss in dB</th>
<th>required mean Tx-power for...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10MBps</td>
</tr>
<tr>
<td>HL</td>
<td>-5</td>
<td>100mW</td>
</tr>
<tr>
<td>HS</td>
<td>-1.7</td>
<td>2.6mW</td>
</tr>
<tr>
<td>MS</td>
<td>-3.7</td>
<td>3.5mW</td>
</tr>
<tr>
<td>LL</td>
<td>-5.5</td>
<td>17mW</td>
</tr>
<tr>
<td>LS</td>
<td>-5.8</td>
<td>4.7mW</td>
</tr>
</tbody>
</table>

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Outlook:

- More data to be evaluated on stratospheric air turbulence and attenuation
- Consider real vibration spectra and attitude stability data from platform tests to further define the requirements
- Further scenarios for opt. links: HAP-Sat & HAP-AirCraft
- Application of coherent transmission to enhance system sensitivity